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Measurements of Test Case F

forced convection, isothermal with contaminants

Heiselberg, Per

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International Energy Agency, Energy Conservation in Building and Community Systems, Annex 20: Air Flow patterns Within Buildings

P. HEISELBERG
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(Forced Convection, Isothermal with Contaminants)
SEPTEMBER 1991

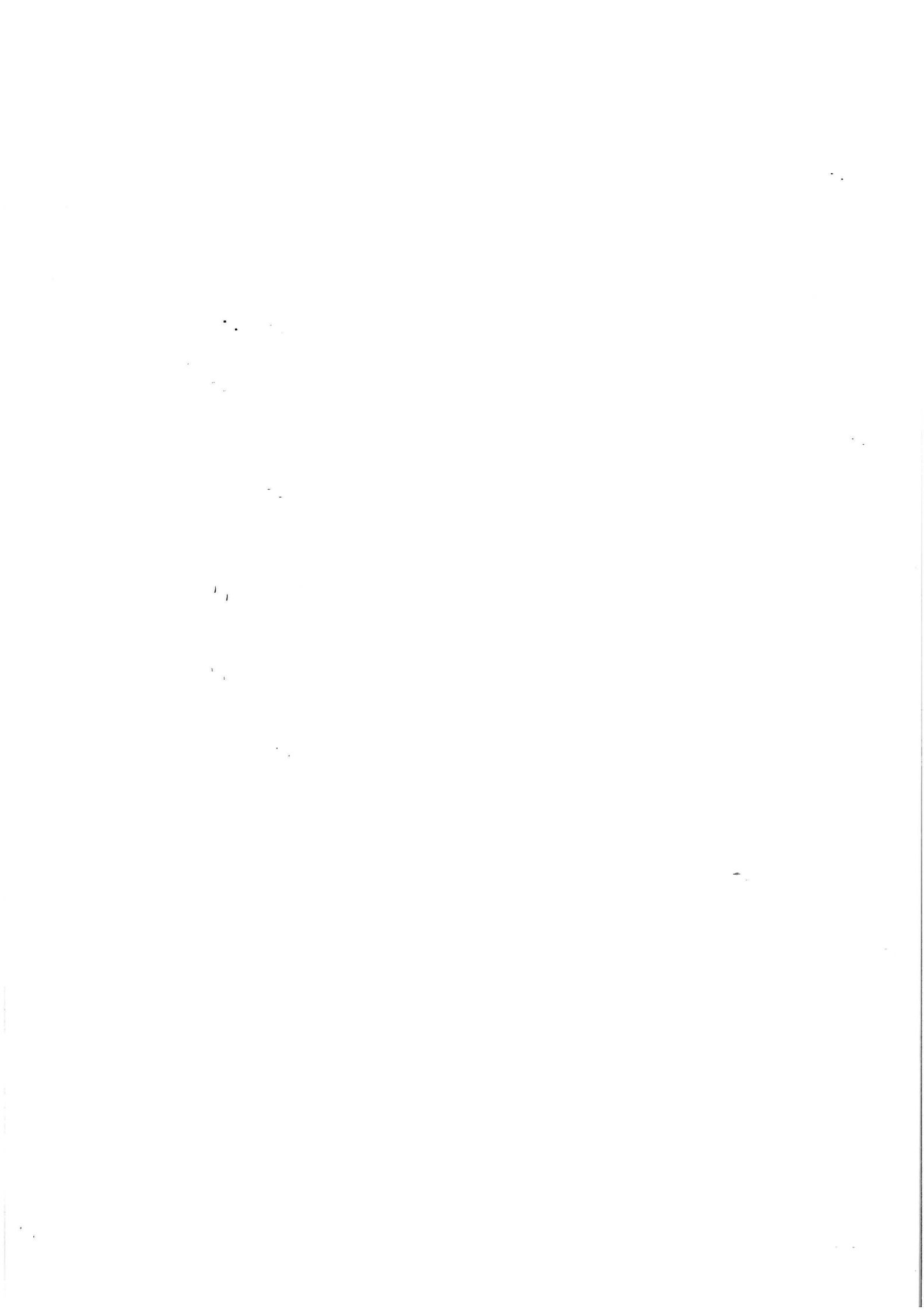
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DEPT. OF BUILDING TECHNOLOGY AND STRUCTURAL ENGINEERING
AALBORG UNIVERSITETSCENTER • AUC • AALBORG • DANMARK

International Energy Agency, Energy Conservation in Building and Community Systems, Annex 20: Air Flow patterns Within Buildings

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RESEARCH ITEM 1.31

MEASUREMENTS OF TEST CASE F

(Forced convection, isothermal with contaminants)

Date: August 1991

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Introduction

This report is a documentation of measurements made at the Department of Building Technology and Structural Engineering at the University of Aalborg. It is a part of our contribution to the work in the IEA - Annex 20 "Air Flow Patterns Within Buildings", subtask 1 "Room Air and Contaminant Flow". One of the objectives of subtask 1 is to acquire experimental data for the evaluation of the performance of numerical air flow models in predicting air velocity, temperature and contaminant distribution in ventilated rooms.

The approach is to make identical full-scale experiments in identical test rooms with identical inlet devices at different sites. Simultaneous numerical simulations for the measured configurations are carried out. The measured data are compared and a data base established for the evaluation of the accuracy of the predictions made.

The report presents the results of a series of full-scale experiments of the contaminant distribution in a test room. The results can be used for comparison with prediction made by numerical air flow models, for comparison with measured data found by other investigators and to show how the contaminant distribution in a full-scale room looks like under different conditions. In the experiments the contaminant distribution has been measured under isothermal steady state flow conditions at different contaminant densities.

The test room

The experiments have been carried out in a standard test room as described by Lemaire¹. The test room is located in a laboratory hall. A sketch of the geometry of the full-scale test room is shown in figure 1. The test room corresponds to the recommended specifications except for the room height of 2.4m (Lemaire¹ specifies 2.5m). The volume of the room is 36.3 m³.

A window is placed in the wall opposite the inlet and outlet devices. The window has a width of 2.0m and a height of 1.6m. The distance from the top of the window to the ceiling is 0.20m.

The inlet device is of the Hesco-type. The diffuser consists of 4 rows with 21 nozzles which can be adjusted to different directions. For these experiments the nozzles have been adjusted to an upward angle of 40°, see figure 1 and Nielsen². The dimensions of the diffuser are (H x W)=(0.17m x 0.70m) and the distance from the ceiling to the top of the diffuser is 0.20m. The generated flow pattern is very typical of modern air terminal device design.

The exhaust device is located below the inlet device at a distance of 1.6m above the floor, see figure 1. The dimensions are (H x W)=(0.2m x 0.3m).

The contamination source consists of a ping pong ball (diameter 30mm) with 6 evenly distributed holes with a diameter of 1mm each. The source was placed approximately in

the middle of the test room in the point $(x,y,z)=(2.2,1.2,0.0)$ as specified by Skåret³. The tracer gas CO_2 has been used as a contaminant. It has been mixed with the carrier gases N_2 or He in order to give a total contaminant flow rate of 0.025 l/s and different contaminant densities.

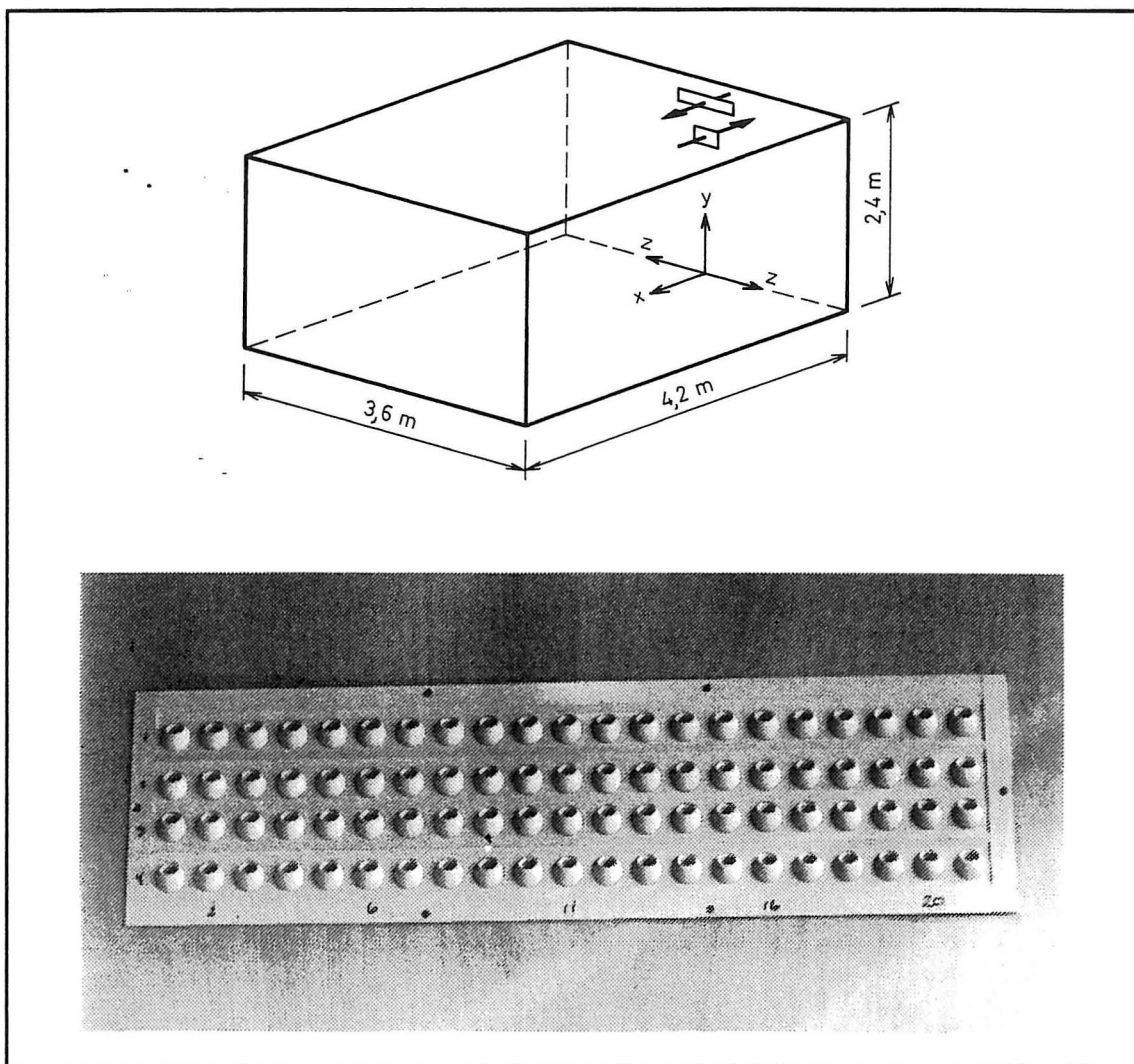


Figure 1. a) Sketch of the geometry of the full-scale test room. b) Close-up of the HESCO inlet device.

The test cases

Three test cases with different density of the contaminant have been carried out, see figure 2. An air change rate of 1.5h^{-1} is selected because this flow rate is approximately the minimum value required to ventilate an office room. Measurements in Skovgaard et al.⁴ show that the throw of the jet is about $4/5$ of the room length and that the maximum velocity in the occupied zone is below 0.1 m/s. The three test cases with contaminant densities of $s=0.8\text{ kg/m}^3$, $s=1.2\text{ kg/m}^3$ and $s=1.8\text{ kg/m}^3$ represent, respectively, a case with low density of the contamination source with a tendency of the contaminant to migrate to the ceiling region, a basic case with neutral density and a case with high

density of the contamination source with a tendency of the contaminant to migrate to the floor region. The complete test conditions are described by Skåret³.

Test Case	Air change rate h^{-1}	Air flow rate m^3/s	Contaminant density kg/m^3	Contaminant total flow rate l/s
f1	1.5	0.0151	0.8	0.025
f2	1.5	0.0151	1.2	0.025
f3	1.5	0.0151	1.8	0.025

Figure 2. The key parameters of the three test cases.

Measurement procedure and measuring equipment

The test room is placed in a laboratory hall with very steady temperature conditions. The supply air was taken from the laboratory hall and the exhaust air was thrown off to the outside. The supply air temperature was controlled by changing the height of the air intake. Temperature measurements in the supply, in the exhaust and in different heights in the test room showed that it was possible to get nearly the same temperature in the test room as in the laboratory hall, a small temperature gradient in the test room and a very small temperature difference between the supply and the exhaust air.

In each test case the contaminant injection and the measurements of the concentrations in the test room were started after isothermal steady state conditions were achieved. The measurements were carried on until steady state contaminant conditions were reached and at least 1-2 hours after. Concentrations were measured in the supply, in the exhaust and in 10 points along a vertical measuring column in the room at the same time. A measuring period of at least 5 min. at each point gives a total measuring period of at least one hour for all 12 points. After measurements at one location of the measuring column, it was moved and concentration measurements were done until steady state contaminant conditions have been achieved for more than 1 hour. The room average concentration was determined by measuring the concentration in the room after a final mixing of the room air after air and contaminant supply were shut off.

In each test case concentrations were measured at 110 points in the centre plane of the test room. Figure 3 shows the distribution of the points. The measuring points were not exactly placed at those locations presented in Lemaire¹. The points were concentrated around the contamination source, where large gradients were expected, at the end wall to see how far the supply air jet would penetrate into the room and at the boundary surfaces. The temperatures in the room were measured in 14 points in different heights above the floor.

Temperatures in the supply, in the exhaust and in the test room were measured with thermocouples of type K connected to a data logger system. The air flow rates were

measured by means of orifice plates. The concentration of contaminants were measured by an IR-analyser connected to a scanning and a data acquisition system.

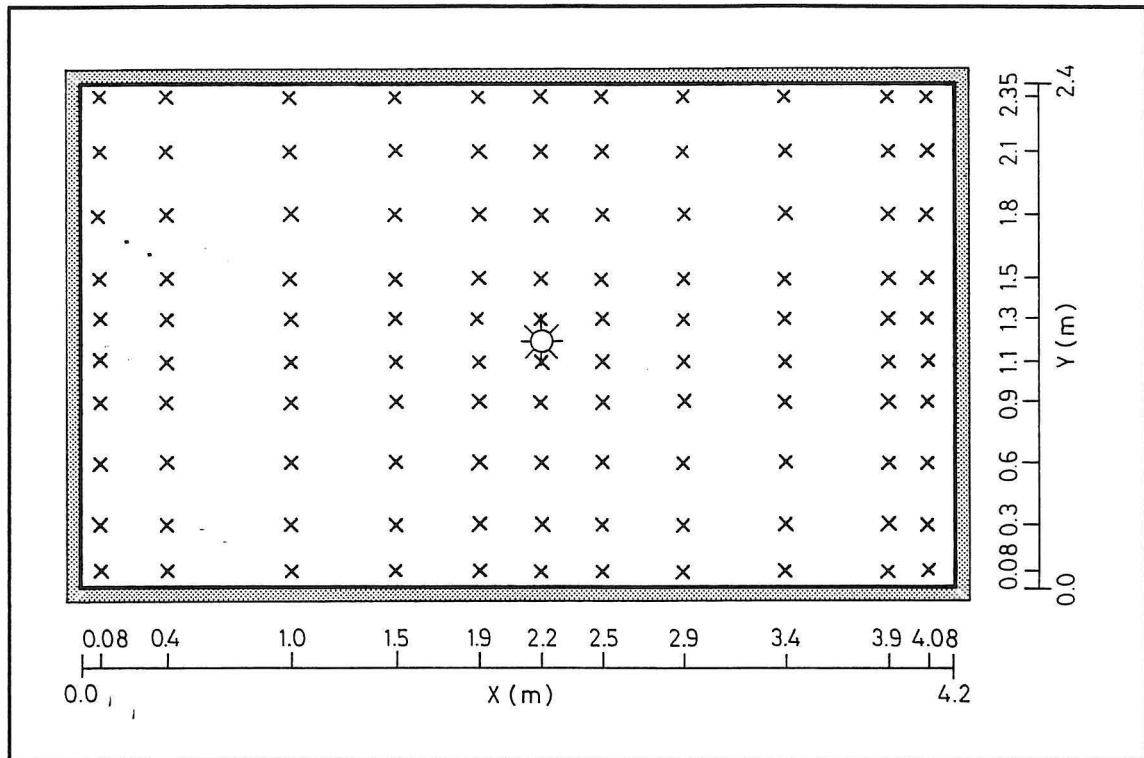


Figure 3. Distribution of measuring points for measurements of the concentrations in the centre plane of the test room.

Presentation of the results

The results of the measurements of the concentrations in the room are presented as concentration ratios where the reference concentration is the concentration in the exhaust opening. The figures 4-6 illustrate the results from the test cases f1, f2 and f3, respectively. The results are shown as contour maps of the relative concentration in the centre plane of the test room. The average ventilation effectiveness for the three test cases is shown in figure 7. The measured temperatures for control of steady state conditions are shown in the figures 8-12.

Contours of concentration

The figures 4-6 show in the upper part of the room just below the ceiling a concentration distribution in the wall jet created by entrainment of the contaminated room air into the primary air. The supply air jet reaches half way down the opposite end wall and the recirculating flow takes place in the upper part of the room above the level of the contamination source. The contours of concentration show considerable differences between the three test cases.

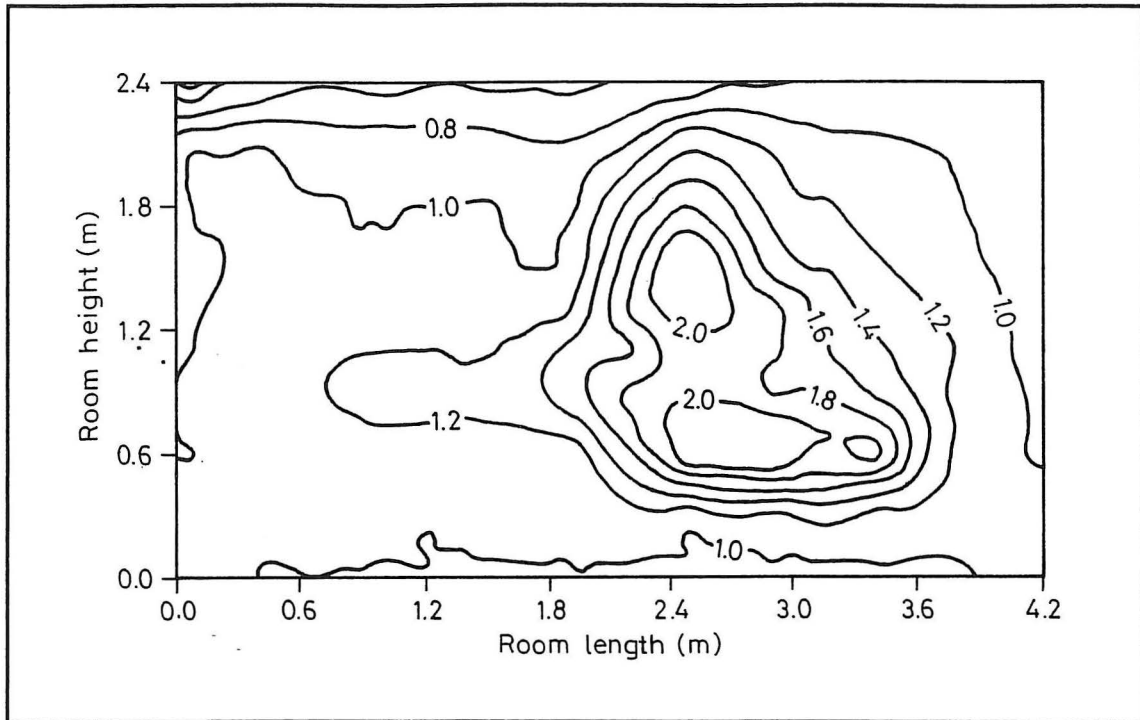


Figure 4. Contours of concentration in the centre plane of the room in test case f1.

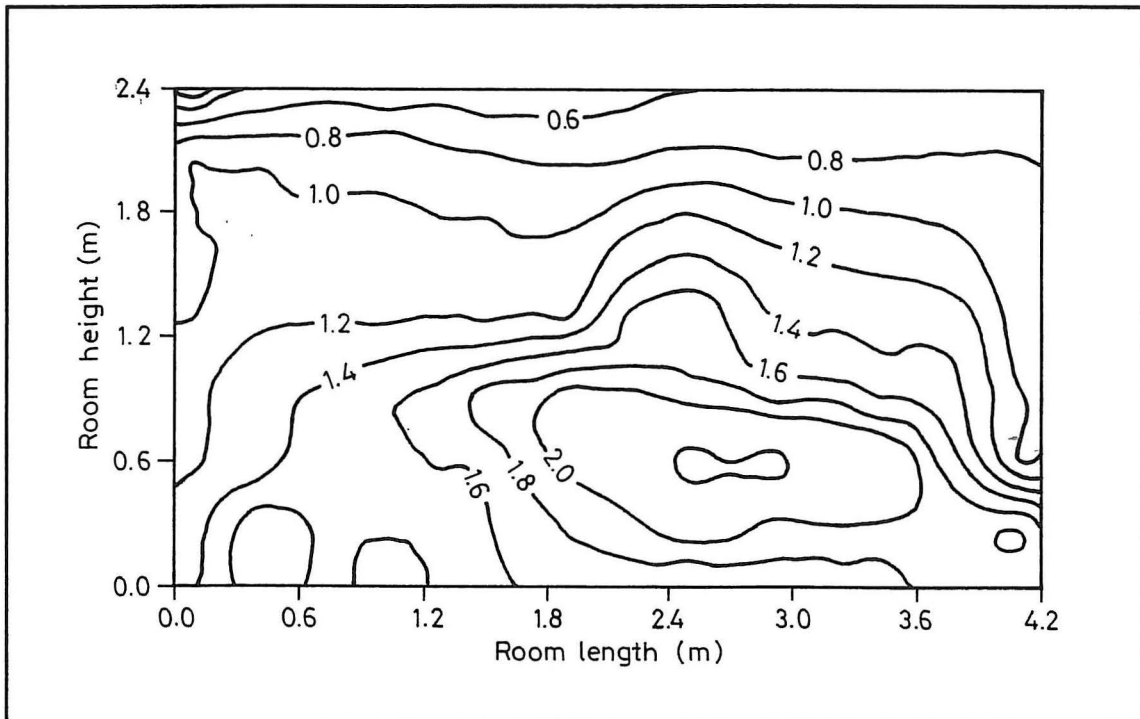


Figure 5. Contours of concentration in the centre plane of the room in test case f2.

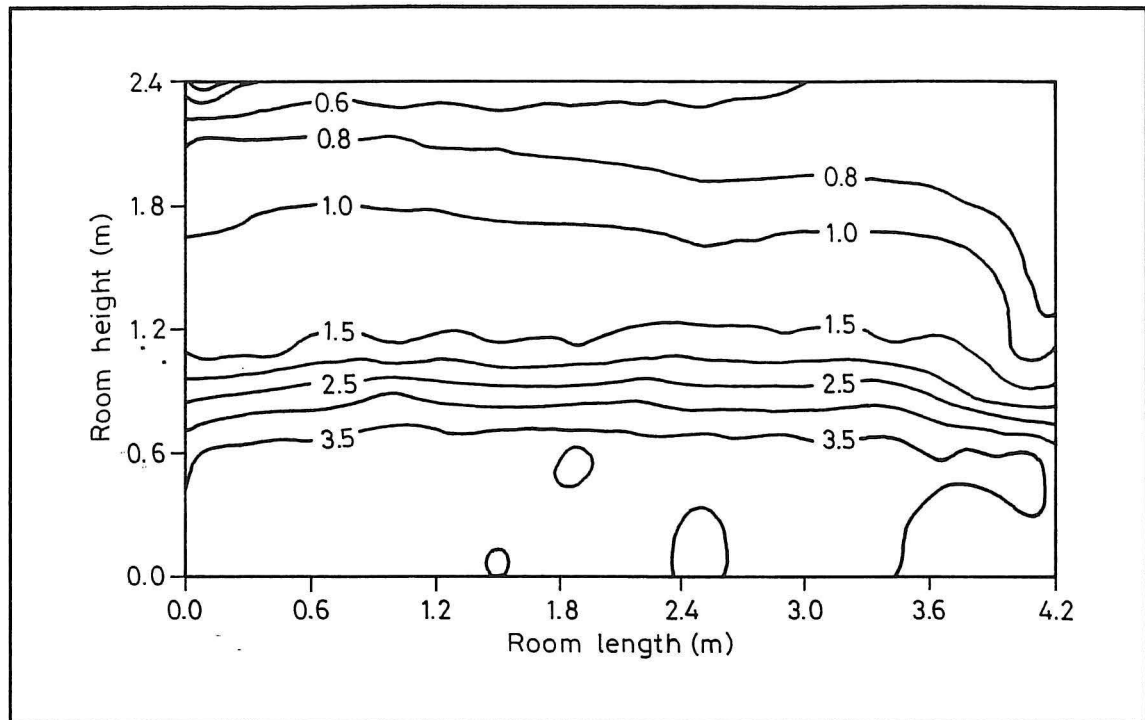


Figure 6. Contours of concentration in the centre plane of the room in test case f3.

Contours of concentration for test case f3, the high density case, in figure 6 show clearly that the contaminant is streaming toward the floor region. Because the supply air jet is not able to flow through the whole room an even stratification of the contaminant arises in the lower part with a large contaminant gradient just below the contamination source. High levels of concentrations appear near the floor because of the low velocities and the slow exchange of air in this region of the room.

Contours of concentration for test case f2, the neutral density case, in figure 5 show that the contaminant distributed to the upper part of the room is mixed with the recirculating room air. The contaminant distributed to the lower part of the room causes a high level of concentration in large areas of the occupied zone for the same reasons as in test case f3.

Contours of concentration for test case f1, the low density case, in figure 4 show high levels of concentration above the contamination source where the contaminant is flowing toward the ceiling and is entrained by the supply air jet. There are also high levels of concentration just below the contamination source.

The considerable differences found between the three test cases will be reduced with an increasing air change rate. The buoyancy effects will decrease and the contaminant distribution will approximate the distribution at high turbulent flow conditions, see experiments in Heiselberg et al.⁵, Heiselberg⁶ and Murakami et al.⁷ This distribution is independent of the air exchange rate, see Nielsen⁸.

It is not possible from the figures 4-6 to see how the three-dimensional flow conditions in the room are influencing the contaminant distribution in the centre plane.

Average ventilation effectiveness

The average ventilation effectiveness has been calculated for the three test cases. The average ventilation effectiveness is for steady state conditions defined as:

$$\langle \epsilon \rangle = \frac{C_e(\infty)}{\langle C \rangle} \quad (1)$$

where $\langle \epsilon \rangle$ is the average ventilation effectiveness
 $C_e(\infty)$ is the average concentration in the exhaust opening
 $\langle C \rangle$ is the room average concentration

The results are shown in figure 7. It is seen that the average ventilation effectiveness is below 1.0 in all three test cases and that the effectiveness decreases with an increase in the contaminant density. The result is typical of ventilation systems with both supply and exhaust at ceiling level and a low air change rate. It supports results found earlier by Sandberg⁹ and Heiselberg et al.⁵

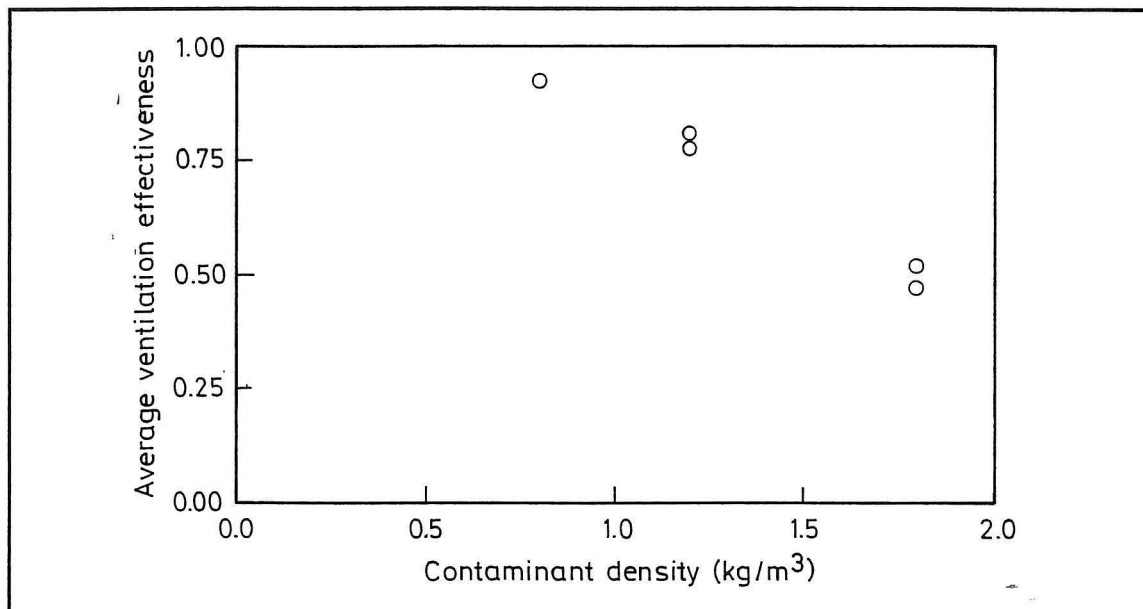


Figure 7. Average ventilation effectiveness for the three test cases f1, f2 and f3.

A ventilation system with an exhaust opening at ceiling level will not always be able to remove a heavy contaminant in a satisfactory way. It often results in a large accumulation of the contaminant in the room, large concentration levels in most parts of the occupied zone, and a low average ventilation effectiveness, see also figure 6.

The average ventilation effectiveness is not only a function of the location of the supply and the exhaust openings and the contaminant density, but also of the air change rate, the location of the contamination source and the supply air temperature, see e.g. Sandberg⁹, Heiselberg et al.⁵ and Rydberg et al.¹⁰

Temperature measurements

The experiments had to be carried out under isothermal conditions and the temperatures were therefore measured in the supply, in the exhaust and in different heights in the test room to make sure that temperature differences were small.

Test Case	$T_{\text{supply}} \text{ (}^{\circ}\text{C)}$			$T_{\text{exhaust}} \text{ (}^{\circ}\text{C)}$		
	$T_{s,\text{min}}$	$T_{s,\text{mean}}$	$T_{s,\text{max}}$	$T_{e,\text{min}}$	$T_{e,\text{mean}}$	$T_{e,\text{max}}$
f1	22.1	22.3	22.5	22.3	22.4	22.5
f2	21.5	21.9	22.3	21.7	22.0	22.4
f3	22.1	22.3	22.5	22.2	22.4	22.5

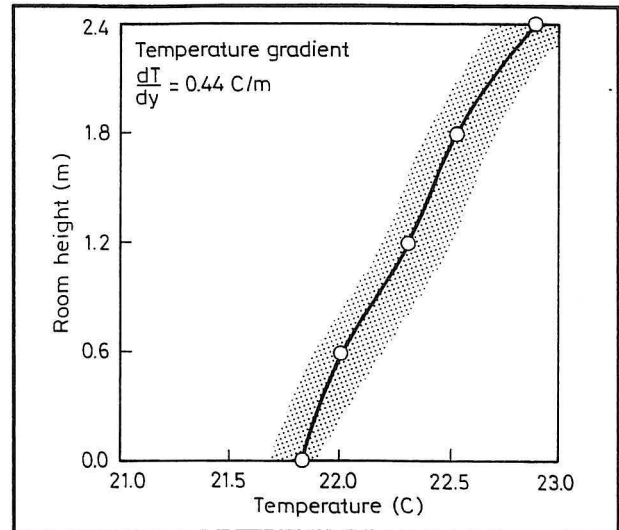
Figure 8. Supply and exhaust temperatures in the three test cases.

Test Case	$(T_{\text{supply}} - T_{\text{exhaust}}) \text{ (}^{\circ}\text{C)}$	Temperature gradient
	$(T_s - T_e)_{\text{mean}}$	$dT/dy \text{ (}^{\circ}\text{C/m)}$
f1	0.14	0.44
f2	0.10	0.41
f3	0.08	0.37

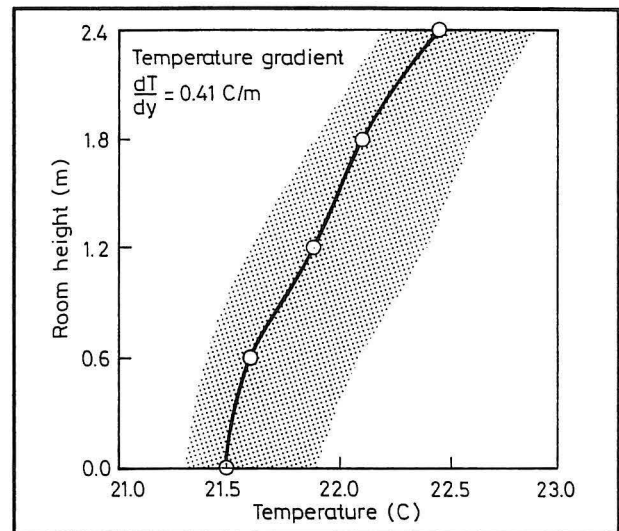
Figure 9. Mean air temperature difference between the supply and the exhaust and the temperature gradient in the test room in each test case.

In the figures 8 and 9 the central temperature parameters are shown for each test case. The supply air temperature is above the temperature range of 19-21 $^{\circ}\text{C}$, as specified by Skåret³. In order to get as isothermal conditions as possible in the test room it was chosen to let the air temperature in the test room follow the air temperature in the laboratory hall and to change the supply air temperature in a way so the least possible temperature difference between the supply and the exhaust was achieved. In figure 8 it is seen that the supply air temperature was varying from 21.5 $^{\circ}\text{C}$ to 22.5 $^{\circ}\text{C}$ and the exhaust air temperature from 21.7 $^{\circ}\text{C}$ to 22.5 $^{\circ}\text{C}$. However, the temperatures were changing very slowly and were following each other. In figure 9 it is seen that the mean temperature difference between the supply and the exhaust air in the three test cases only was varying between 0.08 - 0.14 $^{\circ}\text{C}$. With these small air temperature variations isothermal steady state conditions can be said to have existed under the experiments of the definition in ISO 5129.

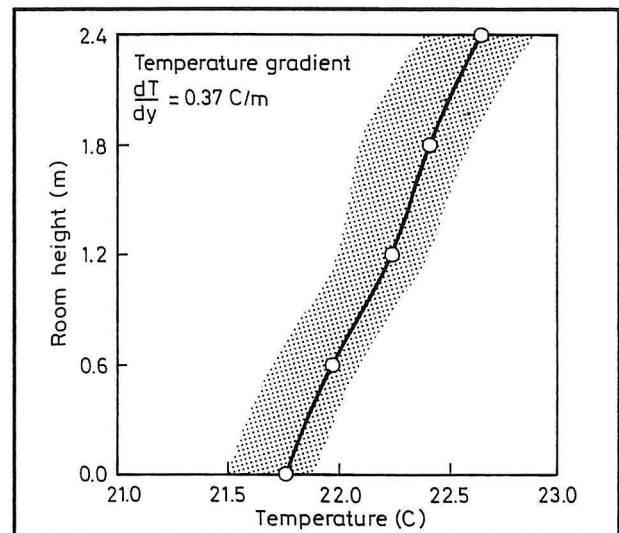
Figur 10. Temperature distribution and temperature gradient in the test room in test case f1. The hatched part of the figure includes the measured maximum and minimum temperatures.



Figur 11. Temperature distribution and temperature gradient in the test room in test case f2. The hatched part of the figure includes the measured maximum and minimum temperatures.



Figur 12. Temperature distribution and temperature gradient in the test room in test case f3. The hatched part of the figure includes the measured maximum and minimum temperatures.



The vertical temperature distribution in the test room is shown for the three test cases in the figures 10-12. They are nearly linear and much alike for the three test cases. The temperature gradients are varying between 0.37 °C/m and 0.44 °C/m giving a total temperature difference between ceiling and floor of about 1°C. The hatched areas show how much the temperatures have varied under the measurements for each test case. The temperature variations were very slow and the temperature distribution in the test room was therefore not changed but only displaced parallel to a lower or higher temperature level.

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Conditons for test : fldk

Research item RI 1.31

Testcase f1

Nature of test: Experimental

Room Dimensions (m):

Height, H= 2.40

Lenght, L= 4.20

Width , W= 3.60

Window Dimensions (m):

Height, Hf= 1.60

Width , Wf= 2.00

Distance of top from ceiling, Df= 0.20

Supply Dimensions (m):

Height, Hi= 0.17

Width , Wi= 0.71

Distance of top from ceiling, Di= 0.20

Exhaust Dimensions (m):

Height, Ho= 0.20

Width , Wo= 0.30

Distance of bottom from floor, Do= 1.60

Flow Rates (m³/s):

Supply , Vs= 0.0151

Exhaust, Ve= 0.0151

Temperatures (C):

Supply , Ts= 22.3

Exhaust, Te= 22.4

Contaminant Characteristics :

Density (kg/m³) = 0.8

Flow Rate (l/s) = 0.025

Results for test : f1dk

Research item RI 1.31

Testcase f1

Nature of test: Experimental

INTERNAL MEASUREMENTS

Number of internal measuring points in x direction : 11

Number of internal measuring points in y direction : 10

Number of internal measuring points in z direction : 1

Coordinates			Dimensionless concentration		Temperatures	
x	y	z	Mean value	Std. Dev.	Ts	Te
0.08	0.08	0.00	1.03	0.04	22.2	22.4
0.08	0.30	0.00	1.05	0.02	22.2	22.4
0.08	0.60	0.00	1.00	0.02	22.2	22.4
0.08	0.90	0.00	1.02	0.06	22.2	22.4
0.08	1.10	0.00	1.00	0.05	22.2	22.4
0.08	1.30	0.00	0.99	0.05	22.2	22.4
0.08	1.50	0.00	0.98	0.04	22.2	22.4
0.08	1.80	0.00	1.00	0.04	22.2	22.4
0.08	2.10	0.00	1.00	0.04	22.2	22.4
0.08	2.35	0.00	0.29	0.02	22.2	22.4
0.40	0.08	0.00	1.00	0.03	22.4	22.5
0.40	0.30	0.00	1.02	0.01	22.4	22.5
0.40	0.60	0.00	1.07	0.02	22.4	22.5
0.40	0.90	0.00	1.15	0.09	22.4	22.5
0.40	1.10	0.00	1.11	0.08	22.4	22.5
0.40	1.30	0.00	1.05	0.05	22.4	22.5
0.40	1.50	0.00	1.02	0.05	22.4	22.5
0.40	1.80	0.00	1.02	0.04	22.4	22.5
0.40	2.10	0.00	1.02	0.05	22.4	22.5
0.40	2.35	0.00	0.54	0.03	22.4	22.5
1.00	0.08	0.00	1.00	0.02	22.1	22.3
1.00	0.30	0.00	1.02	0.02	22.1	22.3
1.00	0.60	0.00	1.05	0.04	22.1	22.3
1.00	0.90	0.00	1.35	0.16	22.1	22.3
1.00	1.10	0.00	1.20	0.10	22.1	22.3
1.00	1.30	0.00	1.08	0.07	22.1	22.3
1.00	1.50	0.00	1.02	0.04	22.1	22.3
1.00	1.80	0.00	0.99	0.03	22.1	22.3
1.00	2.10	0.00	0.94	0.05	22.1	22.3
1.00	2.35	0.00	0.58	0.03	22.1	22.3
1.50	0.08	0.00	1.00	0.02	22.2	22.4
1.50	0.30	0.00	1.01	0.01	22.2	22.4
1.50	0.60	0.00	1.04	0.04	22.2	22.4
1.50	0.90	0.00	1.32	0.19	22.2	22.4
1.50	1.10	0.00	1.16	0.11	22.2	22.4
1.50	1.30	0.00	1.07	0.05	22.2	22.4
1.50	1.50	0.00	1.04	0.03	22.2	22.4
1.50	1.80	0.00	1.01	0.03	22.2	22.4
1.50	2.10	0.00	0.89	0.04	22.2	22.4
1.50	2.35	0.00	0.60	0.02	22.2	22.4
1.90	0.08	0.00	1.00	0.04	22.2	22.5
1.90	0.30	0.00	1.05	0.10	22.2	22.5
1.90	0.60	0.00	1.04	0.03	22.2	22.5
1.90	0.90	0.00	1.55	0.37	22.2	22.5
1.90	1.10	0.00	1.48	0.35	22.2	22.5
1.90	1.30	0.00	1.16	0.13	22.2	22.5
1.90	1.50	0.00	1.04	0.05	22.2	22.5

1.90	1.80	0.00	0.94	0.09	22.2	22.5
1.90	2.10	0.00	0.82	0.04	22.2	22.5
1.90	2.35	0.00	0.59	0.03	22.2	22.5
2.20	0.08	0.00	0.98	0.03	22.1	22.3
2.20	0.30	0.00	1.11	0.14	22.1	22.3
2.20	0.60	0.00	-999.0	-999.0	22.1	22.3
2.20	0.90	0.00	2.05	0.44	22.1	22.3
2.20	1.10	0.00	1.67	0.32	22.1	22.3
2.20	1.30	0.00	1.64	0.39	22.1	22.3
2.20	1.50	0.00	1.75	0.45	22.1	22.3
2.20	1.80	0.00	1.54	0.29	22.1	22.3
2.20	2.10	0.00	0.93	0.24	22.1	22.3
2.20	2.35	0.00	0.61	0.02	22.1	22.3
2.20	0.08	0.00	1.03	0.04	22.2	22.3
2.20	0.30	0.00	1.12	0.08	22.2	22.3
2.20	0.60	0.00	-999.0	-999.0	22.2	22.3
2.20	0.90	0.00	1.71	0.50	22.2	22.3
2.20	1.10	0.00	1.40	0.32	22.2	22.3
2.20	1.30	0.00	2.07	0.43	22.2	22.3
2.20	1.50	0.00	1.65	0.46	22.2	22.3
2.20	1.80	0.00	1.37	0.24	22.2	22.3
2.20	2.10	0.00	1.02	0.20	22.2	22.3
2.20	2.35	0.00	0.69	0.03	22.2	22.3
2.50	0.08	0.00	1.00	0.02	22.4	22.5
2.50	0.30	0.00	1.04	0.04	22.4	22.5
2.50	0.60	0.00	2.21	0.53	22.4	22.5
2.50	0.90	0.00	1.98	0.39	22.4	22.5
2.50	1.10	0.00	1.85	0.32	22.4	22.5
2.50	1.30	0.00	2.22	0.64	22.4	22.5
2.50	1.50	0.00	2.34	0.62	22.4	22.5
2.50	1.80	0.00	1.82	0.39	22.4	22.5
2.50	2.10	0.00	1.38	0.21	22.4	22.5
2.50	2.35	0.00	0.74	0.08	22.4	22.5
2.90	0.08	0.00	1.01	0.02	22.2	22.3
2.90	0.30	0.00	1.06	0.03	22.2	22.3
2.90	0.60	0.00	2.38	0.42	22.2	22.3
2.90	0.90	0.00	1.75	0.32	22.2	22.3
2.90	1.10	0.00	1.84	0.41	22.2	22.3
2.90	1.30	0.00	1.88	0.45	22.2	22.3
2.90	1.50	0.00	1.50	0.34	22.2	22.3
2.90	1.80	0.00	1.29	0.24	22.2	22.3
2.90	2.10	0.00	1.16	0.13	22.2	22.3
2.90	2.35	0.00	0.83	0.11	22.2	22.3
3.40	0.08	0.00	1.01	0.03	22.3	22.4
3.40	0.30	0.00	1.09	0.05	22.3	22.4
3.40	0.60	0.00	2.12	0.45	22.3	22.4
3.40	0.90	0.00	1.52	0.22	22.3	22.4
3.40	1.10	0.00	1.44	0.15	22.3	22.4
3.40	1.30	0.00	1.30	0.10	22.3	22.4
3.40	1.50	0.00	1.23	0.07	22.3	22.4
3.40	1.80	0.00	1.13	0.06	22.3	22.4
3.40	2.10	0.00	1.03	0.05	22.3	22.4
3.40	2.35	0.00	0.86	0.08	22.3	22.4
3.80	0.08	0.00	1.00	0.01	22.3	22.3
3.80	0.30	0.00	1.02	0.02	22.3	22.3
3.80	0.60	0.00	1.13	0.09	22.3	22.3
3.80	0.90	0.00	1.13	0.16	22.3	22.3
3.80	1.10	0.00	1.17	0.14	22.3	22.3

3.80	1.30	0.00	1.11	0.10	22.3	22.3
3.80	1.50	0.00	1.05	0.05	22.3	22.3
3.80	1.80	0.00	1.03	0.03	22.3	22.3
3.80	2.10	0.00	0.98	0.04	22.3	22.3
3.80	2.35	0.00	0.91	0.05	22.3	22.3
3.80	0.08	0.00	1.00	0.06	22.5	22.5
3.80	0.30	0.00	1.06	0.08	22.5	22.5
3.80	0.60	0.00	1.13	0.09	22.5	22.5
3.80	0.90	0.00	1.13	0.15	22.5	22.5
3.80	1.10	0.00	1.21	0.16	22.5	22.5
3.80	1.30	0.00	1.15	0.13	22.5	22.5
3.80	1.50	0.00	1.03	0.10	22.5	22.5
3.80	1.80	0.00	0.99	0.05	22.5	22.5
3.80	2.10	0.00	0.98	0.07	22.5	22.5
3.80	2.35	0.00	0.88	0.08	22.5	22.5
4.08	0.08	0.00	1.04	0.04	22.3	22.3
4.08	0.30	0.00	1.05	0.04	22.3	22.3
4.08	0.60	0.00	1.00	0.03	22.3	22.3
4.08	0.90	0.00	1.01	0.07	22.3	22.3
4.08	1.10	0.00	0.98	0.05	22.3	22.3
4.08	1.30	0.00	0.97	0.04	22.3	22.3
4.08	1.50	0.00	0.96	0.04	22.3	22.3
4.08	1.80	0.00	0.95	0.04	22.3	22.3
4.08	2.10	0.00	0.93	0.04	22.3	22.3
4.08	2.35	0.00	0.87	0.04	22.3	22.3

Conditions for test : f2dk

Research item RI 1.31

Testcase f2

Nature of test: Experimental

Room Dimensions (m):

Height, H= 2.40

Length, L= 4.20

Width, W= 3.60

Window Dimensions (m):

Height, Hf= 1.60

Width, Wf= 2.00

Distance of top from ceiling, Df= 0.20

Supply Dimensions (m):

Height, Hi= 0.17

Width, Wi= 0.71

Distance of top from ceiling, Di= 0.20

Exhaust Dimensions (m):

Height, Ho= 0.20

Width, Wo= 0.30

Distance of bottom from floor, Do= 1.60

Flow Rates (m³/s):

Supply, Vs= 0.0151

Exhaust, Ve= 0.0151

Temperatures (C):

Supply, Ts= 21.9

Exhaust, Te= 22.0

Contaminant Characteristics :

Density (kg/m³) = 1.2

Flow Rate (l/s) = 0.025

Results for test : f2dk

Research item RI 1.31

Testcase f2

Nature of test: Experimental

INTERNAL MEASUREMENTS

Number of internal measuring points in x direction : 11

Number of internal measuring points in y direction : 10

Number of internal measuring points in z direction : 1

Coordinates			Dimensionless concentration		Temperatures	
x	y	z	Mean value	Std. Dev.	Ts	Te
0.08	0.08	0.00	1.32	0.05	21.6	21.7
0.08	0.30	0.00	1.32	0.05	21.6	21.7
0.08	0.60	0.00	1.17	0.12	21.6	21.7
0.08	0.90	0.00	1.16	0.08	21.6	21.7
0.08	1.10	0.00	1.10	0.08	21.6	21.7
0.08	1.30	0.00	0.99	0.06	21.6	21.7
0.08	1.50	0.00	0.97	0.05	21.6	21.7
0.08	1.80	0.00	0.99	0.04	21.6	21.7
0.08	2.10	0.00	0.98	0.05	21.6	21.7
0.08	2.35	0.00	0.28	0.02	21.6	21.7
0.40	0.08	0.00	2.08	0.10	22.0	22.1
0.40	0.30	0.00	2.04	0.11	22.0	22.1
0.40	0.60	0.00	1.29	0.17	22.0	22.1
0.40	0.90	0.00	1.35	0.10	22.0	22.1
0.40	1.10	0.00	1.29	0.09	22.0	22.1
0.40	1.30	0.00	1.16	0.09	22.0	22.1
0.40	1.50	0.00	1.07	0.06	22.0	22.1
0.40	1.80	0.00	1.02	0.05	22.0	22.1
0.40	2.10	0.00	0.95	0.06	22.0	22.1
0.40	2.35	0.00	0.47	0.04	22.0	22.1
0.40	0.08	0.00	1.45	0.06	21.8	21.9
0.40	0.30	0.00	1.39	0.05	21.8	21.9
0.40	0.60	0.00	-999.0	-999.0	21.8	21.9
0.40	0.90	0.00	1.38	0.12	21.8	21.9
0.40	1.10	0.00	1.27	0.09	21.8	21.9
0.40	1.30	0.00	1.13	0.09	21.8	21.9
0.40	1.50	0.00	1.06	0.07	21.8	21.9
0.40	1.80	0.00	1.02	0.05	21.8	21.9
0.40	2.10	0.00	0.98	0.05	21.8	21.9
0.40	2.35	0.00	0.50	0.03	21.8	21.9
1.00	0.08	0.00	1.27	0.10	22.2	22.4
1.00	0.30	0.00	1.46	0.13	22.2	22.4
1.00	0.60	0.00	1.49	0.11	22.2	22.4
1.00	0.90	0.00	1.59	0.31	22.2	22.4
1.00	1.10	0.00	1.39	0.16	22.2	22.4
1.00	1.30	0.00	1.14	0.08	22.2	22.4
1.00	1.50	0.00	1.06	0.06	22.2	22.4
1.00	1.80	0.00	1.02	0.05	22.2	22.4
1.00	2.10	0.00	0.94	0.06	22.2	22.4
1.00	2.35	0.00	0.54	0.03	22.2	22.4
1.50	0.08	0.00	1.56	0.09	22.2	22.2
1.50	0.30	0.00	1.58	0.15	22.2	22.2
1.50	0.60	0.00	1.63	0.12	22.2	22.2
1.50	0.90	0.00	1.92	0.14	22.2	22.2
1.50	1.10	0.00	1.53	0.17	22.2	22.2
1.50	1.30	0.00	1.15	0.08	22.2	22.2
1.50	1.50	0.00	1.07	0.04	22.2	22.2

1.50	1.80	0.00	0.99	0.05	22.2	22.2
1.50	2.10	0.00	0.80	0.03	22.2	22.2
1.50	2.35	0.00	0.53	0.02	22.2	22.2
1.90	0.08	0.00	1.75	0.07	22.3	22.2
1.90	0.30	0.00	1.81	0.12	22.3	22.2
1.90	0.60	0.00	2.07	0.32	22.3	22.2
1.90	0.90	0.00	2.14	0.20	22.3	22.2
1.90	1.10	0.00	1.69	0.27	22.3	22.2
1.90	1.30	0.00	1.18	0.06	22.3	22.2
1.90	1.50	0.00	1.10	0.05	22.3	22.2
1.90	1.80	0.00	0.95	0.05	22.3	22.2
1.90	2.10	0.00	0.74	0.03	22.3	22.2
1.90	2.35	0.00	0.53	0.02	22.3	22.2
2.20	0.08	0.00	1.72	0.08	22.3	22.3
2.20	0.30	0.00	1.79	0.15	22.3	22.3
2.20	0.60	0.00	-999.0	-999.0	22.3	22.3
2.20	0.90	0.00	2.25	0.14	22.3	22.3
2.20	1.10	0.00	1.65	0.24	22.3	22.3
2.20	1.30	0.00	1.72	0.22	22.3	22.3
2.20	1.50	0.00	1.39	0.25	22.3	22.3
2.20	1.80	0.00	1.06	0.17	22.3	22.3
2.20	2.10	0.00	0.74	0.03	22.3	22.3
2.20	2.35	0.00	0.56	0.02	22.3	22.3
2.20	0.08	0.00	1.80	0.10	21.8	21.8
2.20	0.30	0.00	2.01	0.25	21.8	21.8
2.20	0.60	0.00	-999.0	-999.0	21.8	21.8
2.20	0.90	0.00	2.10	0.29	21.8	21.8
2.20	1.10	0.00	1.64	0.29	21.8	21.8
2.20	1.30	0.00	1.58	0.24	21.8	21.8
2.20	1.50	0.00	1.39	0.24	21.8	21.8
2.20	1.80	0.00	1.18	0.23	21.8	21.8
2.20	2.10	0.00	0.78	0.05	21.8	21.8
2.20	2.35	0.00	0.59	0.03	21.8	21.8
2.50	0.08	0.00	1.71	0.09	21.5	21.7
2.50	0.30	0.00	2.20	0.28	21.5	21.7
2.50	0.60	0.00	2.62	0.11	21.5	21.7
2.50	0.90	0.00	1.95	0.21	21.5	21.7
2.50	1.10	0.00	1.71	0.32	21.5	21.7
2.50	1.30	0.00	1.77	0.43	21.5	21.7
2.50	1.50	0.00	1.52	0.28	21.5	21.7
2.50	1.80	0.00	1.22	0.18	21.5	21.7
2.50	2.10	0.00	0.82	0.09	21.5	21.7
2.50	2.35	0.00	0.63	0.03	21.5	21.7
2.90	0.08	0.00	1.75	0.11	21.6	21.7
2.90	0.30	0.00	1.93	0.09	21.6	21.7
2.90	0.60	0.00	2.65	0.15	21.6	21.7
2.90	0.90	0.00	1.79	0.24	21.6	21.7
2.90	1.10	0.00	1.50	0.19	21.6	21.7
2.90	1.30	0.00	1.40	0.17	21.6	21.7
2.90	1.50	0.00	1.32	0.09	21.6	21.7
2.90	1.80	0.00	1.07	0.12	21.6	21.7
2.90	2.10	0.00	0.77	0.07	21.6	21.7
2.90	2.35	0.00	0.63	0.03	21.6	21.7
3.40	0.08	0.00	1.76	0.10	21.6	21.8
3.40	0.30	0.00	1.91	0.11	21.6	21.8
3.40	0.60	0.00	2.45	0.21	21.6	21.8
3.40	0.90	0.00	1.61	0.21	21.6	21.8
3.40	1.10	0.00	1.42	0.10	21.6	21.8

3.40	1.30	0.00	1.33	0.07	21.6	21.8
3.40	1.50	0.00	1.21	0.08	21.6	21.8
3.40	1.80	0.00	1.00	0.09	21.6	21.8
3.40	2.10	0.00	0.77	0.07	21.6	21.8
3.40	2.35	0.00	0.67	0.03	21.6	21.8
3.80	0.08	0.00	1.90	0.10	21.8	21.9
3.80	0.30	0.00	1.97	0.15	21.8	21.9
3.80	0.60	0.00	1.63	0.35	21.8	21.9
3.80	0.90	0.00	1.42	0.31	21.8	21.9
3.80	1.10	0.00	1.38	0.18	21.8	21.9
3.80	1.30	0.00	1.29	0.13	21.8	21.9
3.80	1.50	0.00	1.09	0.09	21.8	21.9
3.80	1.80	0.00	0.96	0.06	21.8	21.9
3.80	2.10	0.00	0.80	0.05	21.8	21.9
3.80	2.35	0.00	0.72	0.04	21.8	21.9
4.08	0.08	0.00	1.95	0.13	21.8	21.9
4.08	0.30	0.00	2.03	0.18	21.8	21.9
4.08	0.60	0.00	0.95	0.04	21.8	21.9
4.08	0.90	0.00	1.04	0.15	21.8	21.9
4.08	1.10	0.00	0.94	0.08	21.8	21.9
4.08	1.30	0.00	0.90	0.05	21.8	21.9
4.08	1.50	0.00	0.89	0.05	21.8	21.9
4.08	1.80	0.00	0.86	0.04	21.8	21.9
4.08	2.10	0.00	0.80	0.04	21.8	21.9
4.08	2.35	0.00	0.73	0.03	21.8	21.9

Conditons for test : f3dk

Research item RI 1.31

Testcase f3

Nature of test: Experimental

Room Dimensions (m):

Height, H= 2.40

Lenght, L= 4.20

Width , W= 3.60

Window Dimensions (m):

Height, Hf= 1.60

Width , Wf= 2.00

Distance of top from ceiling, Df= 0.20

Supply Dimensions (m):

Height, Hi= 0.17

Width , Wi= 0.71

Distance of top from ceiling, Di= 0.20

Exhaust Dimensions (m):

Height, Ho= 0.20

Width , Wo= 0.30

Distance of bottom from floor, Do= 1.60

Flow Rates (m³/s):

Supply , Vs= 0.0151

Exhaust, Ve= 0.0151

Temperatures (C):

Supply , Ts= 22.3

Exhaust, Te= 22.4

Contaminant Characteristics :

Density (kg/m³) = 1.8

Flow Rate (l/s) = 0.025

Results for test : f3dk

Research item RI 1.31

Testcase f3

Nature of test: Experimental

INTERNAL MEASUREMENTS

Number of internal measuring points in x direction : 11

Number of internal measuring points in y direction : 10

Number of internal measuring points in z direction : 1

Coordinates			Dimensionless concentration		Temperatures	
x	y	z	Mean value	Std. Dev.	Ts	Te
0.08	0.08	0.00	3.56	0.09	22.3	22.5
0.08	0.30	0.00	3.61	0.09	22.3	22.5
0.08	0.60	0.00	3.56	0.07	22.3	22.5
0.08	0.90	0.00	2.37	0.23	22.3	22.5
0.08	1.10	0.00	1.25	0.08	22.3	22.5
0.08	1.30	0.00	1.21	0.07	22.3	22.5
0.08	1.50	0.00	1.10	0.05	22.3	22.5
0.08	1.80	0.00	0.92	0.04	22.3	22.5
0.08	2.10	0.00	0.90	0.06	22.3	22.5
0.08	2.35	0.00	0.29	0.02	22.3	22.5
0.40	0.08	0.00	3.87	0.04	22.3	22.3
0.40	0.30	0.00	3.94	0.05	22.3	22.3
0.40	0.60	0.00	3.68	0.09	22.3	22.3
0.40	0.90	0.00	2.78	0.15	22.3	22.3
0.40	1.10	0.00	1.28	0.11	22.3	22.3
0.40	1.30	0.00	1.22	0.05	22.3	22.3
0.40	1.50	0.00	1.11	0.05	22.3	22.3
0.40	1.80	0.00	0.99	0.05	22.3	22.3
0.40	2.10	0.00	0.92	0.05	22.3	22.3
0.40	2.35	0.00	0.48	0.03	22.3	22.3
1.00	0.08	0.00	3.82	0.10	22.2	22.3
1.00	0.30	0.00	3.94	0.15	22.2	22.3
1.00	0.60	0.00	3.85	0.08	22.2	22.3
1.00	0.90	0.00	3.07	0.13	22.2	22.3
1.00	1.10	0.00	1.53	0.16	22.2	22.3
1.00	1.30	0.00	1.30	0.07	22.2	22.3
1.00	1.50	0.00	1.12	0.06	22.2	22.3
1.00	1.80	0.00	0.99	0.04	22.2	22.3
1.00	2.10	0.00	0.87	0.06	22.2	22.3
1.00	2.35	0.00	0.51	0.03	22.2	22.3
1.50	0.08	0.00	3.47	0.07	22.2	22.3
1.50	0.30	0.00	3.56	0.09	22.2	22.3
1.50	0.60	0.00	3.95	0.10	22.2	22.3
1.50	0.90	0.00	2.71	0.16	22.2	22.3
1.50	1.10	0.00	1.53	0.14	22.2	22.3
1.50	1.30	0.00	1.30	0.07	22.2	22.3
1.50	1.50	0.00	1.16	0.06	22.2	22.3
1.50	1.80	0.00	0.95	0.06	22.2	22.3
1.50	2.10	0.00	0.79	0.04	22.2	22.3
1.50	2.35	0.00	0.52	0.03	22.2	22.3
1.90	0.08	0.00	3.77	0.06	22.1	22.2
1.90	0.30	0.00	3.89	0.13	22.1	22.2
1.90	0.60	0.00	4.10	0.14	22.1	22.2
1.90	0.90	0.00	2.72	0.17	22.1	22.2
1.90	1.10	0.00	1.54	0.14	22.1	22.2
1.90	1.30	0.00	1.29	0.09	22.1	22.2
1.90	1.50	0.00	1.14	0.09	22.1	22.2

1.90	1.80	0.00	0.94	0.08	22.1	22.2
1.90	2.10	0.00	0.76	0.06	22.1	22.2
1.90	2.35	0.00	0.55	0.04	22.1	22.2
2.20	0.08	0.00	3.55	0.06	22.4	22.5
2.20	0.30	0.00	3.63	0.16	22.4	22.5
2.20	0.60	0.00	-999.0	-999.0	22.4	22.5
2.20	0.90	0.00	2.51	0.18	22.4	22.5
2.20	1.10	0.00	1.69	0.18	22.4	22.5
2.20	1.30	0.00	1.32	0.09	22.4	22.5
2.20	1.50	0.00	1.13	0.07	22.4	22.5
2.20	1.80	0.00	0.89	0.06	22.4	22.5
2.20	2.10	0.00	0.73	0.03	22.4	22.5
2.20	2.35	0.00	0.56	0.02	22.4	22.5
2.20	0.08	0.00	3.69	0.13	22.1	22.2
2.20	0.30	0.00	3.88	0.23	22.1	22.2
2.20	0.60	0.00	-999.0	-999.0	22.1	22.2
2.20	0.90	0.00	3.16	0.19	22.1	22.2
2.20	1.10	0.00	1.99	0.19	22.1	22.2
2.20	1.30	0.00	1.36	0.22	22.1	22.2
2.20	1.50	0.00	1.16	0.08	22.1	22.2
2.20	1.80	0.00	0.94	0.06	22.1	22.2
2.20	2.10	0.00	0.74	0.04	22.1	22.2
2.20	2.35	0.00	0.58	0.04	22.1	22.2
2.50	0.08	0.00	3.41	0.04	22.4	22.5
2.50	0.30	0.00	3.42	0.04	22.4	22.5
2.50	0.60	0.00	3.87	0.12	22.4	22.5
2.50	0.90	0.00	2.60	0.24	22.4	22.5
2.50	1.10	0.00	1.88	0.27	22.4	22.5
2.50	1.30	0.00	1.28	0.09	22.4	22.5
2.50	1.50	0.00	1.09	0.06	22.4	22.5
2.50	1.80	0.00	0.86	0.06	22.4	22.5
2.50	2.10	0.00	0.71	0.03	22.4	22.5
2.50	2.35	0.00	0.57	0.03	22.4	22.5
2.90	0.08	0.00	3.76	0.11	22.5	22.5
2.90	0.30	0.00	3.72	0.10	22.5	22.5
2.90	0.60	0.00	3.81	0.14	22.5	22.5
2.90	0.90	0.00	2.65	0.32	22.5	22.5
2.90	1.10	0.00	1.70	0.18	22.5	22.5
2.90	1.30	0.00	1.26	0.07	22.5	22.5
2.90	1.50	0.00	1.15	0.04	22.5	22.5
2.90	1.80	0.00	0.89	0.08	22.5	22.5
2.90	2.10	0.00	0.71	0.03	22.5	22.5
2.90	2.35	0.00	0.60	0.03	22.5	22.5
3.40	0.08	0.00	3.59	0.09	22.4	22.4
3.40	0.30	0.00	3.62	0.11	22.4	22.4
3.40	0.60	0.00	3.71	0.11	22.4	22.4
3.40	0.90	0.00	2.85	0.21	22.4	22.4
3.40	1.10	0.00	1.58	0.14	22.4	22.4
3.40	1.30	0.00	1.29	0.08	22.4	22.4
3.40	1.50	0.00	1.18	0.07	22.4	22.4
3.40	1.80	0.00	0.87	0.06	22.4	22.4
3.40	2.10	0.00	0.72	0.03	22.4	22.4
3.40	2.35	0.00	0.63	0.04	22.4	22.4
3.80	0.08	0.00	3.08	0.04	22.2	22.4
3.80	0.30	0.00	3.19	0.07	22.2	22.4
3.80	0.60	0.00	3.63	0.08	22.2	22.4
3.80	0.90	0.00	1.86	0.52	22.2	22.4
3.80	1.10	0.00	1.36	0.28	22.2	22.4

3.80	1.30	0.00	1.35	0.15	22.2	22.4
3.80	1.50	0.00	1.10	0.16	22.2	22.4
3.80	1.80	0.00	0.80	0.06	22.2	22.4
3.80	2.10	0.00	0.71	0.04	22.2	22.4
3.80	2.35	0.00	0.65	0.03	22.2	22.4
4.08	0.08	0.00	3.42	0.07	22.5	22.5
4.08	0.30	0.00	3.51	0.09	22.5	22.5
4.08	0.60	0.00	3.58	0.09	22.5	22.5
4.08	0.90	0.00	1.52	0.58	22.5	22.5
4.08	1.10	0.00	0.85	0.10	22.5	22.5
4.08	1.30	0.00	0.83	0.10	22.5	22.5
4.08	1.50	0.00	0.77	0.06	22.5	22.5
4.08	1.80	0.00	0.73	0.03	22.5	22.5
4.08	2.10	0.00	0.69	0.01	22.5	22.5
4.08	2.35	0.00	0.66	0.01	22.5	22.5

